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An Evaluation of the ASSET Campaign Model in a Regional Antisubmarine Warfare Context

by

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ABSTRACT

This thesis looks at the Antisubmarine Warfare Systems Evaluation Tool (ASSET), written by Metron, Incorporated for OP-71, and how it relates to a current threat environment. ASSET is a campaign level ASW Monte-Carlo simulation intended for developing ASW Master Plans, top-level war fighting requirements (TLWRs), appraisals, and assessments. ASSET, delivered in 1990, was written from a U.S.-Soviet conflict perspective, and needs some restructuring to be able to provide conflict Measures of Effectiveness using platforms that are expected in a regional war. Included as suggested improvements are: a conventional submarine addition with major emphasis on power plant capabilities and limitations; improvements to the surface group-submarine interaction; and improvements and additions to the methods of detection available to the objects in simulation.

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I. THE UNPREDICTABLE FUTURE OF ANTISUBMARINE WARFARE

A. THE CONTINUING NEED FOR STUDY

The last five years have seen major economic, political, and military changes in the world. The collapse of the Soviet Union, the greatest of these changes, not only brought the Cold War to its conclusion, but also forced the Department of Defense to re-justify its existence in terms of the remaining threats around the globe. At present there are few powers other than the Russian Republic and possibly China who can project power to other parts of the globe. With this in mind, national security, defined in terms of threats to our interests, has begun to take a higher degree of relevance, as opposed to possible attacks on allies or on our own shores. Hence was born the regional conflict, the defense planning priority of the 1990's in terms of defense planning.

One of the areas under the greatest attack is Antisubmarine Warfare. Previously, it had been one of the U.S. Navy's highest priorities. It was moved down to reflect the necessity of strike warfare in the regional context, as illustrated in Operation Desert Storm. Much like nuclear weapons however, the submarine was and is a weapon that can truly frighten even the largest of powers, and its proliferation is continuing. The Falklands War demonstrated that even an unbalanced conflict could be quickly equalized with a single modern diesel submarine, making it in the views of many countries a tremendous force multiplier. The impending budget cuts in defense mean that the Department of Defense will have to do as much with less. In-house planning has the Navy shrinking to 450 ships with 10 to 12 carriers and 50 to 70 submarines. This, critics say, is overly

optimistic, predicting fleet level in the 350 ship range. Considering the overhaul and deployment schedules, the Navy will be lucky to meet the national commitments placed upon it. The Chief of Naval Operations' Strategic Studies Group stated in The Future Strategic Environment that:

> The absence of a clear, galvanizing threat combined with our being cash poor, deeply in debt, and uninterested in taxing ourselves means that we need to plan on the basis of having a significantly reduced force structure. This will likely continue until the American public feels threatened by an external force, or until the U.S. is unable to apply military force in a region of major national interest -- at which time the American public will once again demand a bigger defense budget. [Ref. 1:p. 23]

The ability of the Navy to be ready for all possible conflicts in the post Cold War world will be called into question due to limited resources alone. While the basics of naval warfare will not change greatly, the specifics against a plethora of possible adversaries vary tremendously. Consider the antisubmarine warfare case. We know how to perform searches, detect and classify hostile submarines, and launch weapons. However, we may not know the force capabilities of the enemy in terms of maintenance, competence, and in certain cases sheer numbers, due to nothing more than the lack of study. Admiral Sandy Woodward went down to fight the Argentineans with no good bathymetric charts and depending on the current edition of *Jane's Fighting Ships* for a description of the naval strength [Ref. 2:p. 78]. There may not be a clear picture of the acoustic conditions, and how our sonars and weapons will perform in this environment. Is the ambient noise level so high due to merchant shipping the arrays pointed in certain directions are overwhelmed? Will shallow water conditions impede

operations and shorten detection ranges? Unless the Fleet is going to spend money practicing in areas where it simply thinks there may be a conflict, which is unlikely, the only credible alternative is to study the various situations using pencil, paper, and computers with available data.

There are three objectives to this thesis:

- Describe the ASSET model and review the critiques it has received from the many organizations that depend on such models for use in the various studies contracted by the Navy.

- Propose the direction that ASSET should go; that is, to reflect in it the kind of warfare we will most frequently encounter, regional warfare, instead of open ocean battle. The regional scenarios are proving to be much more complex than a lesser included case of blue water warfare.

- Suggest ways to incorporate some basic, necessary, regional features in the existing architecture.

B. THE ASSET SIMULATION

ASSET is a Monte-Carlo campaign model developed for the Chief of Naval Operations (OP-71), and is intended for use in developing ASW Master plans, top-level war fighting requirements (TWLR), appraisals, and assessments. From the ASSET technical documentation:

> ASSET is a totally integrated analysis tool with embedded models for C3I, undersea and overhead surveillance, submarine operations, MPA operations, and mine warfare. The program is structured so that all program features can be used in a mirror-image fashion to model both Blue and Red capabilities. Both prehostilities and hostilities are considered; during prehostilities ASW unit

> confine operations to track and trail. During hostilities, weapon release is authorized, and ASW units attempt to convert detections to kills. [Ref. 3:p. iv]

ASSET was written in the LISP computer language, employing object oriented programming techniques, in order to allow "modules" of models to be added or removed depending on the need for them. This is the great advantage of this programming method, since it sets up a hierarchical relationship between objects depending on the needs of the simulation. For example, a "submarine" object could inherit a "sonar" object that has specific detection characteristics. The drawback to LISP is that it is not widely known and fairly hard to learn. Other languages such as C and Pascal also have object language extensions, and are much more commonly known, and may be easier to learn. Future versions of ASSET will likely be written in C++ for the Sun workstations.

1. What ASSET addresses

As a campaign simulation, ASSET has a lot to offer. The program is large in scope, including:

- Command, control, communications intelligence networks including both GENSER and SI message traffic, which are completely customizable by the user for the scenario;

- Marine patrol aircraft (MPA), including sonobuoy fields, command structures, maintenance failures, and logistics and maintenance;

- Submarine operations, including sub-on-sub interactions for both prehostilities and during hostilities, logistics, own ship acoustic parameters, detection parameters and command structures;

- User definable minefields;
- SURTASS ships, which are included in the C3I network;
- Satellite, and HFDF detections;
- Fixed area sensors, such as a SOSUS array, and tripwires;
- Surface groups, with a group acoustic signature, to serve as targets for enemy submarines.

Even with this long list of attributes, many could find items that they would prefer to see added, prior to running their particular scenario. Some existing functions are also not without problems. This simulation has been under scrutiny for about two years, and the potential user organizations have compiled some "wish lists", as well as some criticisms of certain parts of the model.

2. Critiques of ASSET

The ASSET program was submitted to OP-71 in the middle of 1990 for evaluation and eventual use in the ways mentioned above. OP-71 then passed it to the Center for Naval Analyses (CNA), and the Naval Postgraduate School (NPS) for evaluation and Systems Planning and Analysis (SPA) for practical use, if possible, in Chief of Naval Operations sponsored studies. Each has looked into the architecture of the program and found it to have virtues, but all have mentioned specific deficiencies in the program which could and should be corrected to provide a more realistic simulation for planning objectives. There is a good deal of commonalty among the concerns, and from these one can acquire a general sense for the way that ASSET or a possible successor will need to go to be more useful in a post-Soviet world.

a. Center for Naval Analyses (CNA)

The Center for Naval Analyses has been reviewing the ASSET model for over a year at the request of OP-71. The report by CNA was completed in early 1992, and was submitted to Metron for comment. The CNA report review process requires that reports not be quoted until complete. However, there are some non-specific areas that some of the CNA analysts had comment on.

Both CNA and OP-71 are looking for a good regional simulation to replace previous and inferior models. CNA maintains, however, that one simulation cannot be all things to all people. Simulations as large as ASSET often make difficult to justify assumptions about how changes on a tactical level affect an outcome of a battle or a war. The size itself may alone be a major problem. Modeling assumptions critical to a user may be overlooked in the technical documentation, not to mention the errors in coding that may stay hidden. Specific uses are in the designer's mind when the simulation is programmed. For example, if a user has no interest in a specific and elaborate command, control, and communications network, there may be serious drawbacks to using ASSET because a great deal of processing time goes toward the manipulation of the networks. A similar complexity criticism applies to McDonnell Douglas' SCAT model. It was built to simulate ASW aircraft tactical performance, but was extended to include submarine approaches and attacks on a carrier battle group. SCAT may not be the simulation of choice if simplicity and transparency of the aircraft and ship modeling is desired.

The lack of communication and defense capability in the surface groups is also is a major problem. These "punching bag" groups would appear to preclude the use of ASSET in any study requiring surface interactions.

b. Systems Planning and Analysis (SPA)

Systems Planning and Analysis is a firm that performs many of the ASW studies for OP-71. In interviews with analysts working there [Ref. 4], other items were mentioned for desired addition to the current architecture. The first was the inability of the program to allow a submarine to radiate multiple frequencies, and thereby be tracked on one or more of them. This would more closely model reality; tracking is done with the strongest, highest, and most stable frequency available. Unfortunately, if completely implemented with a decision algorithm the tracking algorithm would become immensely more complex, slow the program and would increase many times the amount of data that had to be entered.

The second desired feature was that of active sonar, preferably a good model of both high or medium frequency and the upcoming low frequency. Metron has a scaled back version of ASSET which has a Low Frequency Active (LFA) model, but was for internal use only, and was not for distribution to OP-71, and subsequently not to anyone who may need it for analytic work, which may indicate a weakness in it. Active sonar brings a myriad of problems with it, including the necessity of modeling target strength, two way transmission loss, acoustic power, and the determination of noise limited and reverberation limited cases, false contacts, classification problems, and therefore false prosecutions.

An optional "cookie cutter" model of detection range was also desired by the analysts at SPA. This would greatly simplify the amount of data that needed to be entered, since all that would be needed is the maximum range

of detection, and would bypass the entire propagation loss entry procedure. If the contact was within the given range, detection would occur.

As CNA had mentioned, the lack of a battle group model was also a serious drawback to the analysts at SPA. Many current studies involve the battle group and its vulnerability to attack, and the lack of a functional battle group model made the program unusable, except from a standpoint of counting how many times the submarine came within weapons/encounter range of the generic surface group. This is true for both the torpedo and submarine launched cruise missile cases.

c. Naval Postgraduate School (NPS)

The Naval Postgraduate School has done to date four theses involving ASSET, all of which proposed ideas to make the simulation more realistic.

- Richard M. Shaffer evaluated the MPA detection and allocation models [Ref. 5]. He concluded that ASSET gains speed by sacrificing some accuracy at the tactical level in order to keep a reasonable speed of execution in the program. Sonobuoys were uniformly placed in the search area, negating any potential benefits from different pattern geometries. To correct this he proposed two detection models which employed user-selected sonobuoy patterns with actual buoy locations specified. The first uses a user-defined pattern with a fixed probability of detection, while the second replaces the continuous sensor field with a glimpsing sensor. Another problem he noted was that submarines are constrained to remain inside or outside the MPA search area and were not

allowed to cross the boundary during the search. Finally, there was no provision for a relief MPA to maintain contact on a detected submarine.

- Paul W. Vebber analyzed the Kalman Filter based Maneuvering Target Statistical Tracker embedded in ASSET, and made some suggestions for improvement [Ref. 6]. He recommended changes aimed at decreasing the computation time including:

- Use of modified equations to compute the actual filtered variance and position of the target.

- Filtering the variance of the contact distribution prior to conducting a random draw, thus producing a position drawn from a distribution approximating that of the actual filtered position variance. This allows appropriate values for the sensor areas of uncertainty to be pre-computed for a range of expected time intervals.

- Limiting the situations where the filter is actually used to those which will result in a meaningful amount of information being extracted.

- Using planar estimations of the latitude and longitude computations rather than perform the conversions on a "spherical earth."

- Shawn M. Callahan evaluated detection modeling in ASSET, and found that the glimpse rate model used could be improved [Ref. 7]. A glimpse rate, g, is currently a required ASSET input. Probability of detection can be highly sensitive to the choice of g. Also change in relative speed, lateral range, or environmental conditions apparently requires a different g. The many different possible target trajectories dictate that many different glimpse rates might be required to derive a consistent probability of detection. To correct this, he

proposed a Lambda-Sigma Glimpse Rate Model which gave the following advantages:

- Glimpse-to-glimpse correlation of signal excess is provided.

- It approaches the Lambda-Sigma Model as glimpse rate approaches infinity.

- It maintains the current ASSET glimpse rate structure.

- It provides more realism in the thin convergence zone case.

- Peng-tso Chang actually altered the original ASSET code to replace the Glimpse Rate Model with the above Lambda-Sigma Jump Model [Ref. 8]. Additionally, he made the following changes:

- A target's most detectable frequency and detection rate were allowed to vary with environmental region.

- Multiple engagements between platforms were allowed.

- Richard Shaffer's second model for sonobuoys was implemented, using a glimpse rate model to determine detection opportunities of MPA and to approximate a continuous looking sensor.

- ASSET was modified so that MPA were allocated to SPAs so as to maximize the ratio of the MPA's time-on-station to the SPA size. If fuel allowed, the MPA would stay on station after a submarine prosecution for another detection opportunity.

d. Metron, Inc.

The creators of the model have recognized the need to alter or expand its capabilities. The programmer, Steve Lent, has written a Programmers

Guide [Ref. 9] for the Postgraduate School, including, as examples, two modules that improve ASSET.

The first improvement allows a variable radiated noise, which permits detectability to depend on not only the speed of the object and the environment, but also on transient noise emissions from the platform.

The second improvement is an addition of a measure of effectiveness (MOE) to record the detection range at the time of detection. Over many runs, the MOE would allow the computation of an average detection range.

There are other modifications that Metron is working on for the final version of the Programmer's Guide. The most significant of these is an maritime patrol aircraft "hand-off" model, in which an MPA that must depart due to logistical reasons, leaves only when a relieving MPA has been cued. This is much more desirable since a real MPA would not leave the area prior to such a turnover.

Finally, Metron's comment on the lack of an interactive surface group was that, while they felt its exclusion was significant, the problem was simply too complex to address when ASSET was being designed. An adequate level of detail could not be agreed upon to accurately and completely model the approach, attack, detection, attack and counterattack of a surface action group. The thought was that if a measure of effectiveness (MOE) was needed, one could count torpedoes or detections.

C. SIMULATING AN ASW REGIONAL CONFLICT

Considering all the comments on ASSET, there is an obvious need for some additions to make it more useful to analysts and to senior officers, and to give

rapid feedback to a previously unpredictable regional, "green water" scenario. The primary units in the ASW fight in the future that should be expected are the torpedo firing, diesel submarine, friendly nuclear submarines, the maritime patrol aircraft, and some form of surface action group. To take ASSET into this context, three categories need to be added or modified to reflect the current ASW battleground.

1. The Conventional Submarine

Probably the simplest of the three additions to implement, the ubiquitous non-nuclear submarine will be a great threat to a battle group, task force, or merchant fleet. Its differences from a nuclear submarine are important, not only in terms of it size and quietness, but also due to the extreme variability of exploitable detection opportunities, both acoustic and non-acoustic. Future variations in the power plant configurations, including air-independent propulsion, fuel cells, and Stirling engines, will make the non-nuclear submarine a very potent threat.

2. The Battle Group

Generally regarded by all reviewers as one of the most incomplete features of ASSET, the surface group model requires considerable improvement. This is probably the hardest change to make to ASSET, depending on the level of detail that is attempted, since it may involve bringing in a battle group or task force commander, MPA that may operate with the surface group, detection capabilities of individual units, high value units, and many other factors. As difficult as these modeling issues are, they should be addressed. The current modeling of surface forces is very incomplete.

3. The Detection Methods

The most all-encompassing deficiency is that of detection methods. With many non-acoustic methods of detection deployed, including radar and magnetic anomaly detection (MAD), the non-nuclear submarine is and will be easier to detect than a nuclear submarine. Active sonar should also be modeled, since quiet submarines may make that the prominent method of acoustic detection by surface forces in the future.

II. THE CONVENTIONAL SUBMARINE

One of the most prominent units in the future years that we can expect is the non-nuclear submarine. Its affordability by ambitious nations and its flexibility make it the most useful sea denial platform available. To that end, it is crucial that this platform be considered in future studies and simulations to allow both its capabilities and vulnerabilities to be taken into account. In its present form, ASSET does not include a conventionally powered submarine model, only that of the nuclear powered attack submarine. To use the nuclear powered model and its parameters would overestimate the ability of the non-nuclear submarine, and would not give the multiple detection opportunities that its power plant limitations would allow. The argument can be made, however, that the non-nuclear submarine capabilities will approach that of the nuclear powered submarine as more development is made by the exporting countries. In any event, there are great differences in the two types, where they fight, how they fight, and their respective vulnerabilities.

A. NUCLEAR SUBMARINE CHARACTERISTICS

To see what modifications to ASSET and possibly other simulations would be necessary to accurately model the operations of a non-nuclear submarine, the nuclear powered submarine model must be reviewed to see if any parameters are consistent for both, as well as differences that may need to be expounded on. While the operations may have similarities, the means and the specific details may be completely different.

1. Actual Nuclear Submarine Operations and Characteristics

The nuclear powered submarine has few basic variable external characteristics that are important in modeling concerns. Since it has the ability to remain underwater for an extended period of time (greater than three months) due to the nuclear power plant, atmosphere processing equipment, and water distillation systems, there is no need for prolonged periods on the surface or at periscope depth. Also, barring maintenance failures of crucial components, all speeds obtainable by the submarine can be sustained and are available upon demand, again by virtue of the power plant. There are a few remarkable elements to note however, since they involve detection issues that carry over to the non-nuclear submarine.

Exposure at the surface would only be due to the need to communicate with the outside world, and that would involve a periscope and possibly an antenna. This communication period is somewhat fixed, depending on the schedule to which transmitted messages are repeated and when navigation satellites are available for precise fixes. The length of this period is highly variable, depending on the means by which the transmitted, i.e. Ultra High Frequency (UHF), High Frequency (HF), or Very Low Frequency (VLF). The data transfer rates at the lower frequencies are slow enough to cause the ship to spend a great deal of time at periscope depth. The exception to this process is, of course, the floating wire which is designed for reception of VLF transmissions. The presence of the wire would permit the submarine to only need to expose a mast for an active transmission, which in ASSET would only occur for a passive detection.

Atmosphere control is also handled within the submarine itself. Oxygen generators, CO_2 Scrubbers, and CO-H_2 Burners, take care of most important atmosphere concerns. Ventilation, although often desired, is not necessary for crew survival or performance, and therefore is not necessary for modeling consideration. A non-nuclear submarine may have to consider this possibility, if snorkeling is not a tactical option, given that battery life is not the limiting consideration.

Most acoustic detection by the nuclear powered submarine is done passively via a hull spherical array, a conformal array, or through some type of towed arrays. Active transmissions through radar or sonar are unwise in a covert role since they may give away the ship's position or presence, and hence may not need to be modeled for the submarine object. The passive detection opportunities are the primary means that submarines have for initial detection, tracking, localization, classification and targeting. Electronic Support Measures (ESM) are also extremely important for knowing that a threat or a target is nearby. These models need to not only exist, but be complete to the degree that correct action by the submarine commander is taken upon receipt.

The acoustic signature of a nuclear submarine is more pronounced than that of a typical non-nuclear submarine running on the battery. The coolant pumps, turbine generators, and various other auxiliary pumps put sufficient sound in the water to reduce any acoustic advantage over a non-nuclear submarine to nearly zero. The problem is that the sound will occur in many, different frequency bands and the tracking algorithm gets proportionally more complex and time consuming as it comes closer to representing true operations.

2. ASSET's Model of a Nuclear Submarine

Figure 1 is a screen copy of the menu which defines in ASSET the object of a nuclear submarine. It is very comprehensive, to the point of requiring specific sonar parameters for defining both the ship's sonar and the noise that the ship gives off in both a slow and fast speed.

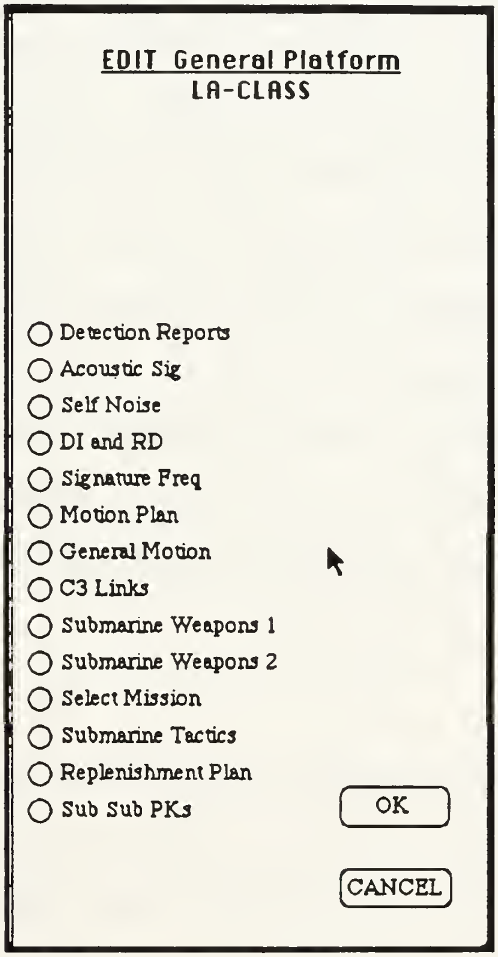

Figure 1. Screen shot of ASSET's Submarine Definition Menu

Communication networks are defined, motion plans are built and specified (including those for replenishment), weapons loadouts are initialized,

target types are established, and sub versus sub probability of kills are tabulated. Both the class and specific platforms are edited from this menu.

There are some somewhat serious problems with the model of the nuclear submarine in ASSET. Only two speeds can be defined with their corresponding signature noise levels at a single frequency. By allowing only two speeds the programmer is taking from the simulation the option a commander would have to use only the speed required to complete the attack, in order to retain as much stealthiness as possible. Also, only allowing the submarine to attack or trail either surface ships or other submarines invalidates the entire flexibility of the modern attack submarine to choose the target of opportunity. Finally the probability of kills are generic for one type of submarine against another. No consideration is made for condition situations which may alter the outcome probabilities, such as who detects first, salvo tactics, attacker bearing relative to the target or a host of other considerations. This would require more data entry, but may reflect the true outcome of the melee, and its conditional dependence on how it is entered.

B. BASIC CONVENTIONAL SUBMARINE CHARACTERISTICS

Any country that operates submarines regularly has a variety of platforms and capabilities and sizes in its fleet. This is true in both nuclear fleets and in the non-nuclear fleets. Despite this, there are many commonalties within each type of platform. Table 1 relates the basic configurations of the most common or modern submarines that may be encountered.

TABLE 1. COMMON NON-NUCLEAR SUBMARINES AND THEIR BASIC CAPABILITIES [Ref. 10]

SUBMARINE	Displ. tons	Length(m)	Beam(m)	Subm Speed(kt)	Torpedo Tubes/ Torpedoes	Surfaced Range(NM)	Subm Range(NM)	Depth (m)
KILO	3000	73	9.5	17	6 - 53 cm 18	20000 @ 11 knot		300
FOXTROT	2500	91.5	8	16	6(f), 4(r) - 53cm 22	16000 @ 8 knots		250
TYPE 209 (1100)	1210	54.5	6.2	21.5	8 - 53 cm 14			250
TYPE 209 (1200)	1285	55.9	6.3	22	8 - 53 cm 14	6000 @ 8 knots	400 @ 4kn 230 @ 8kn	250
TYPE 209 (1500)	1850	64.4	6.5	22	8 - 53 cm 14	13000 @ 10 knot		260
TR1700	2264	66	7.3	25	6 - 53 cm 22	12000 @ 8 knots	460 @ 6 knots	270
DAPHNE	1038	57.8	6.8	16	8 - 53/55 cm(f) 4 - 53/55 cm(r) 12	10000 @ 7 knots	450 @ 5 knots	300

This table shows the large variety of platforms distributed throughout the world. We see in this table that the possible threats come in a wide variety of sizes, ranges, and weapons. In all cases the power plant and battery determine the overall level of threat posed by these ships.

Analysis of the non-nuclear submarine require details not needed for the nuclear submarine analysis. Most of these are related to detectability issues that are a function of the limitations of the power plant and the variability of noise levels.

The power plant is the key to the performance of the ship: The combination of the diesel engines and large, specially designed batteries. Since there is an electric drive, submerged propulsion is extremely quiet and hard to detect. In this propulsion method, however, is the limitation of how far and how fast the battery is discharged. If a high tactical speed is desired, the total energy in the battery available is consumed much faster than if a slow speed was ordered, roughly on the order on the cube of the speed. To recharge the battery snorkeling at periscope depth or on the surface is required, since this is the only method of placing energy in the battery.

During the recharging process, the submarine is to a large degree noisier than its submerged running mode, exposes a large mast to radar detection, and puts a fair amount of waste heat energy into the water.

The primary issue that therefore needs to be addressed is to derive a good approximation to a battery-diesel propulsion system. If one was to assume a simple indiscretion rate model, that is,

$$\text{indiscretion rate (\%)} = \text{time spent snorkeling} / \text{time in transit} \times 100\%$$

where the submarine snorkeled for some fixed percentage of the day, then no consideration would be given to energy limitations on the battery when running at various speeds and force snorkeling even if there is an imminent threat. The

only good way to investigate the vulnerability and the flexibility of the non-nuclear submarine is to model, as completely as possible, the power plant and battery combination. If the power plant is modeled, the detectability and threat concerns will fall out as natural functions of how often it would have to snorkel, and how far and how fast it could go.

C. NECESSARY MODELING CONSIDERATIONS FOR A CONVENTIONAL SUBMARINE

The goal of a model of a foreign non-nuclear submarine is that the model should be simple, accurate, and utilize data that is available to the analyst. If the model is complete, but requires some great level of detail requiring highly classified data, the model will get little use. In the development of a propulsion methodology the major sources are *Jane's Fighting Ships* and some unclassified documents from the foremost non-nuclear submarine designer, Howaldtswerke-Deutsche Werft (HDW) [Ref. 11] and the complimentary battery designer Hagen [Ref. 12]. This is necessary so that ASSET can remain an unclassified model that is not prohibitively hard to use due to inaccessibility.

1. Propulsion and Speed Issues

In a non-nuclear submarine model, speed is a function of tactical necessity, initial charge level of the battery, number of alternators available for power transfer, and the amount of energy the electric propulsion motor is able to draw to put energy in the water. In the more advanced submarines that are testing air-independent propulsion (AIP) methods, the input of this auxiliary power plant can provide enough energy to indefinitely remain submerged,

though the submarine may be limited by the need for navigational data, communication information, or the submarine atmosphere.

Since this "function" has so many variables and is very complex, the simplest method of modeling a non-nuclear submarines is from analyzing actual data. Most standard parameters of a particular submarine can be obtained from *Jane's* as shown in Table 1. Although actual submarine performance is hard to obtain, HDW will upon request put out a fact sheet including submerged ranges at given speeds for the Type 209 (1200), while Hagen will provide battery energy characteristics at specified discharge levels.

Tom Stefanick put forth in *Strategic Antisubmarine Warfare and Naval Strategy* a method [Ref. 13:pp. 141-145] by which non-nuclear submarine range can be predicted. The first step is to compute the power consumed by skin friction drag on the submarine as it moves through the water at various speeds. The equation he uses to predict this amount of power is:

$$U = K\left(\frac{P_s}{LD}\right)^{\frac{1}{3}}$$

where U is the speed of the submarine in knots, K is a constant (25 for single screw ships), P_s is the shaft horsepower, L is the length in feet, and D is the diameter of the submarine in feet. This power, in combination with "hotel loads" (those loads comprising lighting, sonar, and computer power and other non-propulsion electrical loads), battery weight, and the specific energy capacity of the battery will allow the prediction of the running time of the submarine at a specific speed. This is done adding all the power required to operate the submarine, finding how much energy the battery contains, and the dividing the

power needed by the battery energy to find out the running time. The weak spot in the method are the assumptions that battery weight is a fixed percentage of the total tonnage of the submarine which can be overcome if more specific data on the submarine is available. The key assumption in this method is the value for the specific energy in the battery. Although his was not designed to be a dynamic model, Stefanick assumes a median value for a typical German submarine battery. The numbers for specific energy are not that easy to pin down for a variety of speeds, and range from 20 to 50 watt-hours/kilogram for the same battery for different discharge rates. Figure 2 below shows the power available from the battery for a specific discharge rate, normalized for weight computed from the Hagen data. Also, this curve is fairly easy to fit as a power curve.

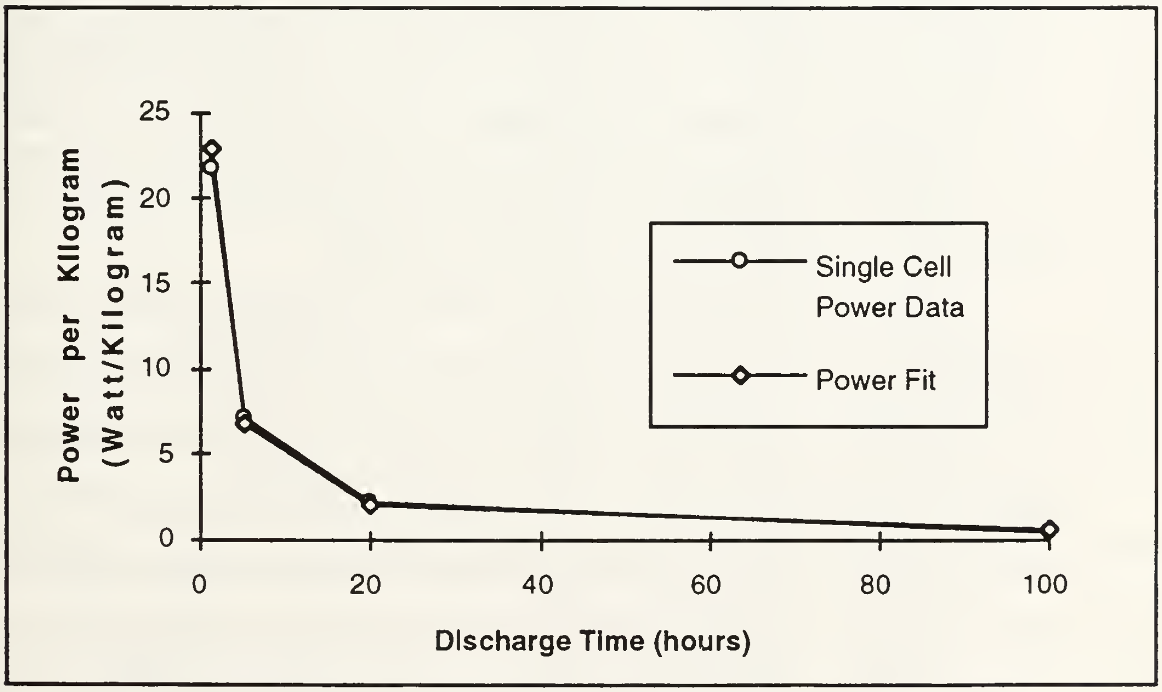

Figure 2. Power Available from the Battery at Various Discharge Rates

Please note that Figure 2 has the time divided out from the ordinate, to show how well the curve has been fit, and the units are therefore watts/kilogram. If time is kept in Figure 2, then the graph would show more energy available at longer discharge times (or another way, lower discharge rates).

Since we do have the specific energy curve for a typical German battery, one approach to predicting submarine performance might be to simply apply the curve that can be fit to the battery energy data to Stefanick's method. Unfortunately, looking at the Type 209 (1200) data, the curves bear little similarity to each other. The explanation for this lies in the nonlinearities that lie between the battery and the propeller, in terms of energy flow. Propeller efficiency, electrical losses, and other losses will skew the prediction. Another problem with this method is that the time discharge rate and the actual time that the battery is discharged are not always the same. A more reasonable approach would be to take a submarine performance curve, fit a function to it, take out the specific details of that particular submarine, and then use the resulting "specific energy" curve to predict other submarine behaviors.

We will take data provided by HDW on the performance of the Type 209 (1200) and normalize it by going backwards through Stefanick's method to find the specific energy characteristic of a generic battery, with appropriate non calculable considerations thrown in. Table 2 contains these calculations. The first two columns contain the data as obtained from the HDW document, adding new entries for an expanded table. In the third column, we took the data and fit to it the closest function possible, by the method in the CRC Standard Mathematical Tables [Ref. 14:p. 510], to make a function from which any speed

input will give the submerged run time. The resulting function, was an exponential curve of the form:

$$\text{Submerged Time} = (266.20536)(.775788)^{\text{speed}}$$

TABLE 2. NORMALIZATION CALCULATIONS TO FORM EMPIRICAL "SPECIFIC ENERGY" CURVE

Speed Knots	Data-Run Time Hours	Predicted Run Time Hours	Power To Drive KW	Total Energy KW	Battery Energy WH/Kg
2		160.21	1.69	51.69	31.70
4		96.42	13.52	63.52	23.44
4.5	91.1	84.93	19.24	69.24	22.51
6	61.7	58.03	45.61	95.61	21.24
8	33.7	34.93	108.12	158.12	21.14
10		21.02	211.18	261.18	21.01
12	10.8	12.65	364.92	414.92	20.09
14		7.61	579.48	629.48	18.34
16	4.37	4.58	864.99	914.99	16.05
18		2.76	1231.60	1281.60	13.53
20		1.66	1689.44	1739.44	11.05
21	1.42	1.29	1955.74	2005.74	9.89
22		1.00	2248.65	2298.65	8.79

The fourth column is a computation of the power required to drive the submarine from the Stefanick equation with a straight 85% propeller efficiency figured in. The fifth column is this power plus 50 KW of hotel loads from the HDW sheet. Finally, the sixth column is the conversion of the power required by the submarine at each speed to the normalized energy of watt-hour/kilogram, with the stated remaining charge of 20% divided out. The computation was the fifth column converted to watts, multiplied by the time of the battery run, divided by the 80% of the weight of the battery (to account for remaining energy). Below is the Figure 3 which shows how the specific energy relates to speed.

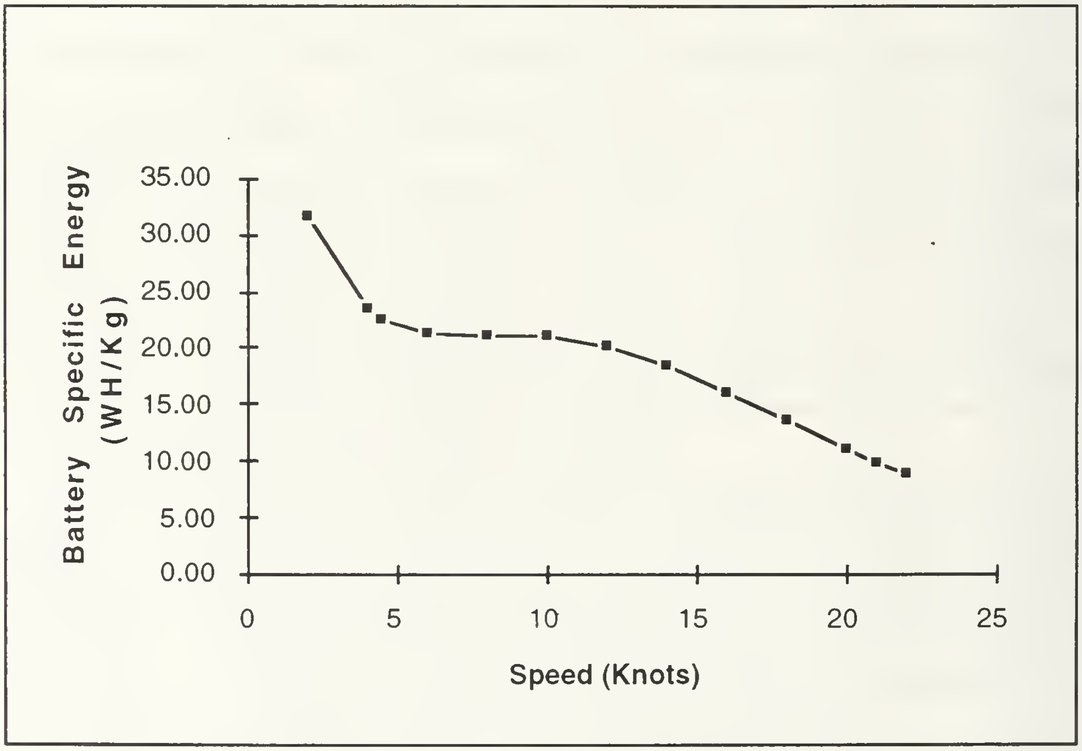

Figure 3. Resulting Normalized Battery "Specific Energy" Curve

Notice that the hotel loads at the lower speeds rival and beat the power needed to drive the submarine, which accounts for the nonlinearity in the graph.

Now that we have a curve for the submarine's energy, we will want to apply this to another submarine to see how ASSET might use this data to give a reasonable motion model. From *Jane's* there is data regarding the KILO class non-nuclear submarine:

Weight: 3076 tons

Dimensions: 243.8 x 32.8 feet

We will assume, as Stefanick does, that battery weight is 20% of ships weight, that we will only run to 80% discharge on the battery, and that hotel loads on this large ship require 100 kilowatts. All calculations have been performed in Table 3. The first calculation is to use the Stefanick equation to determine the power to drive the ship and divide by 0.85 to account for propeller efficiency. Next, add 100 to that number to account for hotel loads which gives the total power. Finally, take the value from our "specific energy" curve for a desired speed, multiply it by 80% of the battery weight in kilograms and divide by the total power required. The result is the run time at that speed. Figure 4 is a graph of the results of our sample computation. The results appear reasonable. Now, knowing the speed and time allowed by the battery, points can be computed by ASSET where the submarine would have to come to periscope depth to begin snorkeling.

TABLE 3. COMPUTATION OF THE RUN TIME OF A KILO CLASS SUBMARINE AT VARIOUS SPEEDS

Speed (knots)	Battery Energy (WH/Kg)	Power to Drive (Kilowatts)	Total Energy (Kilowatts)	Predicted Run Time (hours)
2	40.06	4.82	104.82	170.64
4	31.42	38.53	138.53	101.26
4.5	30.80	54.87	154.87	88.80
6	30.86	130.05	230.05	59.89
8	32.57	308.28	408.28	35.62
10	33.50	602.10	702.10	21.30
12	32.63	1040.43	1140.43	12.77
14	30.12	1652.16	1752.16	7.68
16	26.52	2466.20	2566.20	4.61
18	22.44	3511.45	3611.45	2.77
20	18.38	4816.80	4916.80	1.67
21	16.46	5576.05	5676.05	1.29
22	14.65	6411.16	6511.16	1.00

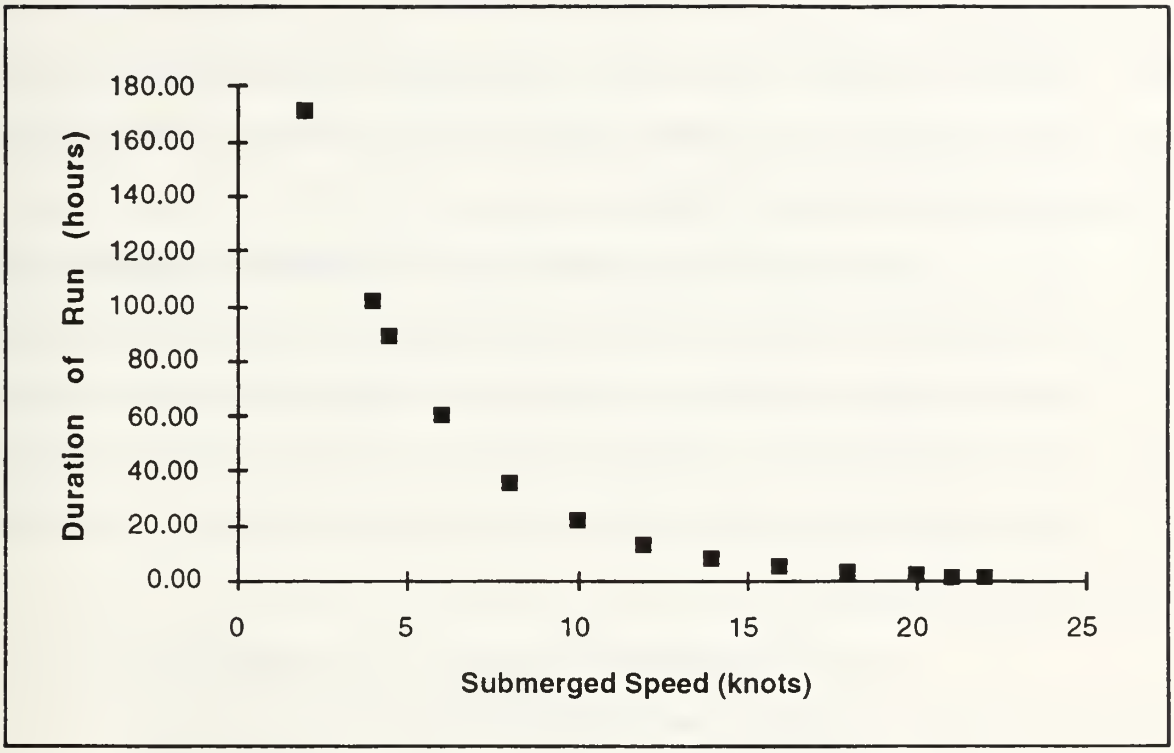

Figure 4. Results of the Run Time Prediction of the Kilo Class Submarine

2. Detectability Issues

From the shallow submarine comes opportunities for detection. To model these opportunities, all that should need to be input would be depth at which the submarine snorkels, a time limit on the crew for atmosphere ventilation, and the amount of noise, in terms of source level, that the diesel makes.

3. Additional Power Plant Concerns

Figure 5 is a diagram from the Hagen Battery pamphlet which shows a typical operation on a standard diesel electric submarine. It is significant because

it shows that the ship will transition to periscope depth fairly often to snorkel for battery recharging. It may not actually represent every detail but since it is from submarine battery designers, these most likely represent the parameters from which the battery was designed.

The question for the model is to what degree the variations in speed can be modeled. A battery will put out more energy on a slow discharge than on a rapid discharge, and this is reflected in the battery specific energy. But to make the speed transition in a simulation requires that an assumption be made on how much of the battery is left to discharge. One way to do this is to use the kilowatt-hours as a counter.

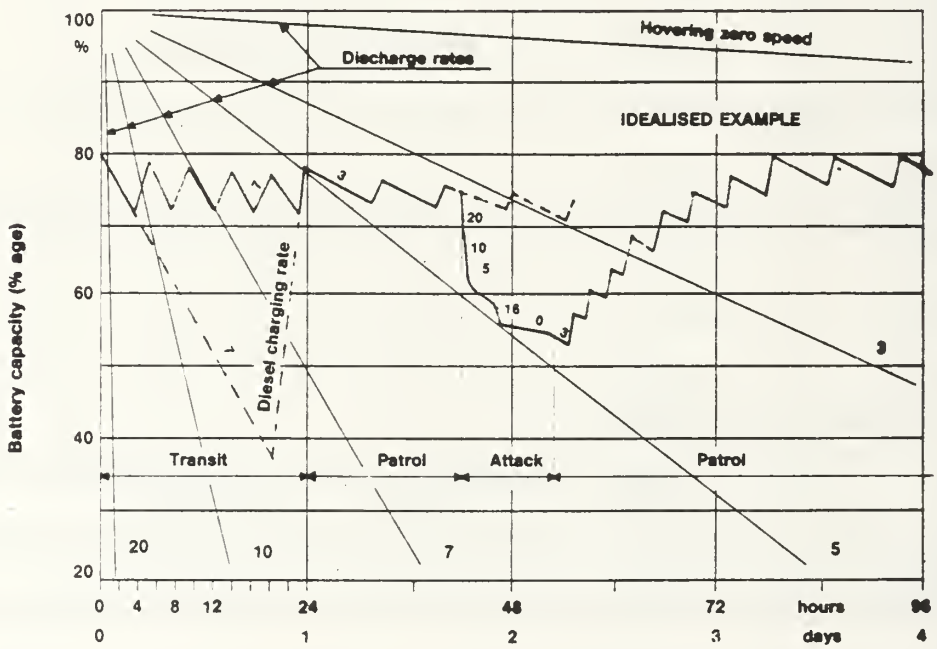

Figure 5. Example Diesel Submarine Operating Profile

Given there is some level to which the battery should not be discharged below (as in 80% in the calculations above), knowing how long the submarine

was run at some speed can be converted to kilowatt-hours. Knowing the original battery specific energy, multiplying it by the original weight of the battery will result in total kilowatt-hours. The used portion can be subtracted from the original portion to yield remaining kilowatt-hours. Knowing the next speed will take the calculation into a new specific energy and total energy to compute time available at that speed. The kilowatt-hours left are known, the kilowatts required to drive the sub at a speed are known, and from those time left on the battery at a speed can be determined. This can be repeated for a different speed. The end will come when the kilowatt-hours are used and the submarine snorkels or sinks. At the point of snorkeling, the submarine should shift to a louder source level and use a transmission loss curve computed for this shallow source.

As for air independent propulsion, the contributions of each system are given in kilowatts. Since we know the power to drive the sub at some speed, the AIP system's contribution is merely subtracted from the total power required to drive the submarine. The battery's kilowatt-hours are then used to find the time at this speed. This is not entirely an accurate approximation, since the drain on the battery will be much less, and therefore the total output in kilowatt-hours of the battery will be much higher.

4. Future Technology Considerations

In the near future, many technological improvements will have been made to the non-nuclear submarine. The AIP systems may become much more commonplace, allowing almost constant submerged operations. Atmosphere processing equipment and precision navigation equipment will become necessities as the time underwater increases. As the captain of the U-1 noted

debriefing a 44 hour test of the new fuel cell system "During a submerged transit I felt the urgent need to be able to dispose of a navigation system independent of the periscope depth." Also in the offing are extra acid batteries, fluctuating snorkel masts, automation of the control surfaces, and permanent magnetic motors. These should be minor tweaks to an established non-nuclear model.

III. THE SURFACE GROUP

A. THE EXPECTED ROLE OF THE BATTLE GROUP IN U.S. DEFENSE

Most experts see the aircraft carrier's role in power projection remaining well into the future, but not necessarily always being the center of every battle group. In "The Way Ahead," Former Secretary of the Navy Garrett states:

> Our carrier battle groups and amphibious ready groups are the cornerstones of our forward deployed forces, and will remain so. These supremely independent forces can be tailored to include varying numbers and mixes of tactical aircraft, surface combatants, submarines, logistic support ships, and Marine air-ground task forces...During the 1990's we expect to adjust the composition of our carrier battle groups and amphibious ready groups routinely, to suit specific situations...Often, we will be operating with smaller battle groups, particularly as our older surface combatants are replaced by fewer- but more capable cruisers, amphibious ships, and destroyers. [Ref. 15]

In fact, the crucial groups of the future conflict may not be the carrier group at all, instead simply merchants. Much of the future threat discussion is centered on the vulnerability of various types of surface ships to third world submarines. On the other hand, the battle group of the future may not have the ASW capability that the present groups do. If one goes to a missile cruiser as the center of the group, then already a good number of MPA have been immediately removed from consideration.

The representation of a surface group, whatever its composition, in a campaign simulation is crucial. The continuing use of surface groups in high

visibility power projection roles with strict rules of engagement makes them a high payoff target to a would-be attacker. The loss or damaging of any ship in a relatively small conflict would be an extremely high price to pay, and consequently, the vulnerability prior to the conflict must be ascertained. The first merchant that ends up on the bottom would cripple trade in the area for a prolonged period, as others would not dare to venture in to a proven hostile area. As was mentioned earlier, the specifics can be wildly different from one scenario to another, but the surface interaction is going to be integral to the conflicts of the future.

B. ASSET 1.0 AND SURFACE ENGAGEMENTS

The initial version of ASSET has a very simple surface model. A surface group has four basic parameters that define it. Figure 6 is a screen shot of the introductory screen by which this definition process begins. The surface formation, like the submarine, is primarily an acoustic radiator with a motion plan. A source level is defined for a slow and a fast running speed at one particular frequency. The formation will follow an exact motion plan that is specified by the user in an earlier phase of the simulation setup in which a track to follow is precisely laid out. The surface formation may patrol in an area or transit. There is no way to specify number of units in the formation that may be subject to engagement. There are instead rules defining how the encounter will proceed and a definition of the measure of effectiveness on the encounter. The ASSET Technical Documentation defines the surface engagement MOE to be the total number of engagements of surface forces by opposing submarines up to a

specified point. There is a user defined critical range at which the submarine is counted a having engaged a surface formation.

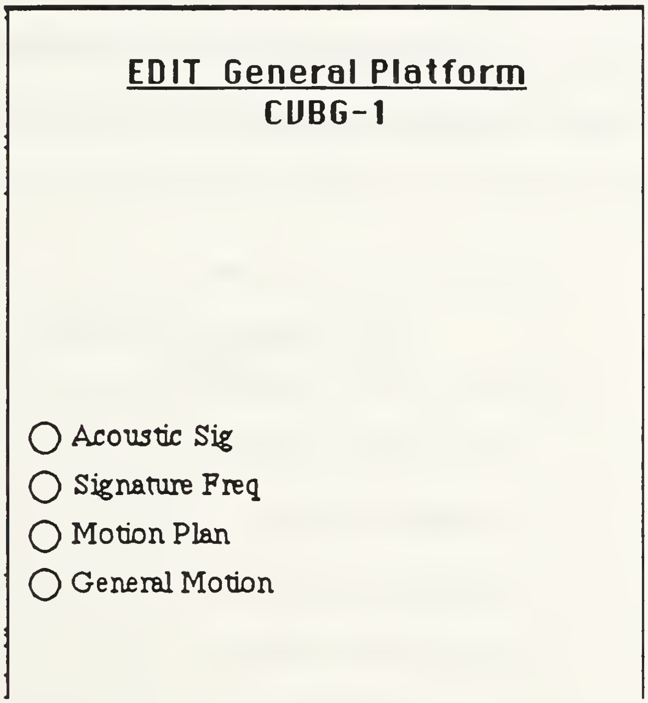

Figure 6. Surface Formation Definition Menu

Also, the Antisurface Warfare (ASuW) Intercept Threshold is defined as the amount of time that a submarine which detects a surface formation will take to attempt to intercept it, i.e. get to the critical range. These numbers are generic for any submarine-surface ship engagement for each side. Figure 7 is the menu by which general motion parameters are defined. Most of the blocks are self-explanatory. The Patrol Speed and Patrol Leg Time are the parameters of motion that ASSET uses to generate motion within a user defined patrol region. The Patrol Speed is the speed at which the surface group moves when it is in a region in its motion plan. Patrol Leg is the parameter of an exponential distribution for

the time between course changes when the submarine is on patrol in a region. In the surface formation definition, however, intercept speed is unused since the formation has no detection capabilities defined, and therefore will not pursue the submarine. The navigation block defines a "1" if the motion plan specified is a Rhumb line, while a "0" means the motion plan is a great circle route.

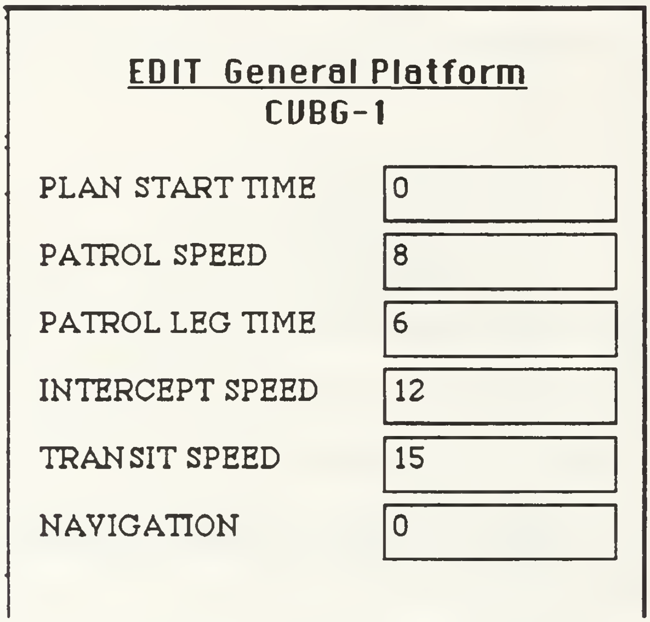

Figure 7. General Motion Parameters for ASSET Surface Formation

For any form of attack in the present version of ASSET, the submarine which makes a detection closes into the user specified parameter of critical range as long as he is not in an tail chase that lasts longer than the threshold specified by the user. Once at the critical range, the submarine will launch cruise missiles or torpedoes up to the limits set in the submarine definition, and then will disengage.

A serious weakness is that the submarine may then re-detect the surface formation and move in again to repeat the attack. Since no surface ships sink, no counterattack is made, no alert message is sent to the C3I network, and no effort is made to attack, hold down, or evade the submarine, it is artificial and unrealistic for continual re-attacks on the battle group. Realistically, even an unescorted merchant ship or convoy would send a submarine position report to both MPA and other ASW forces.

C. NEW VULNERABILITIES IN A REGIONAL SETTING

Knowing what ASSET cannot handle, let us look at what a good campaign model should be able to handle to cover the details of future conflicts. Some features have been pointed out above that would be nice to incorporate, such as communication networks, detection capabilities, and some reasonable amount of ASW and anti-ship missile defense (ASMD). Certain aspects of the regional conflict expose more glaring and serious defects in the model for the CALOW/ Low Intensity Conflict study. We will first describe the environment and then show the ASW play that is needed.

1. The Multi-level threat

The task force or battle group commander must be prepared to deal with a multi-level threat: attacks from the surface, above it and below it. To take all into consideration is a difficult task in reality, as it is in a campaign level model. Screens are often defined from a singular predominant threat, and are weaker in dealing with other threat axes and types, such as a anti-air warfare/ anti-surface screen might not be optimized for ASW. In regional war this problem is nothing if

not exacerbated. Being closer to the enemy's home waters, with specified rules of engagement that allow no fire unless fired upon, the problem becomes much more difficult. The threat axis close to a coastline could be anywhere along that coast. All enemy weapons, even the short range conventional submarines can be brought to bear. No longer will the U.S. have the luxury of standing off outside the maximum range weapons if aircraft have to fly deep inside the country to get at the objectives of the war.

From the ASW standpoint, the multilevel threat means that the distraction level in the surface group will be very high. With an informal national priority not to tolerate the loss of lives in combat overseas, many of the future scenarios will focus on use of missiles and air power to quickly overwhelm enemy air and ground forces and meanwhile maintaining a tight defensive posture. The assumption is that unless there is some perceived direct submarine threat or unaccounted for local submarines, then submarine defense will be more point defense, instead of actively going out and attempting to locate and destroy. Resources that one could normally commit to a strict submarine problem may also have other more pressing uses. For instance, a carrier's flight deck may not have the capability to handle large numbers of fixed wing ASW aircraft on top of an already pressing strike. This is assumption is good for a simulation, since it allows only ASW in the task force or battle group itself, and not externally reaching MPA from the battle group. However, limits may have to be imposed on the ability of the group to conduct self defense operations, based on the need for strike missions or AAW.

2. Effect of Sustained MODLOC

In combination with the multi-level threat is the need to be in a fairly restricted area for a sustained period, be it self imposed or due to geographical constraints. One of the primary vulnerabilities of surface units is the ability to have their position determined with adequate scouting measures, and since they do not move very fast (relative to aircraft and missiles), their position can be tracked fairly easily. In a constrained environment, this problem is much worse. For example, if ships are needed to remain in the Persian Gulf, or in the far eastern part of the Mediterranean to support air operations, this alone makes them vulnerable to units that can fix and report their position. Also, if electronic emissions control is not maintained, which is not likely in an air operations environment, then one should expect exploitation of this signal intelligence to aid in fixing the location of the formation, as well as drawing in searching units, including submarines with quality ESM receivers.

If the area is acoustically shallow, detection of quiet submarines will be virtually prohibited. This, in combination with a prolonged stay, may mean certain trouble for the surface group.

3. Effect of Non-nuclear powered, Torpedo Firing Submarines

The conventional submarine brings a profound threat to the regional battle. Not only is it an extremely quiet platform, but also carries a solid punch in the form of its heavyweight torpedoes. Putting this platform in an acoustically difficult area may result in ASW defenses chasing many false targets.

Due to the conventional submarine's quiet nature and small aspect, active sonar will most likely have to be employed to find it. The environment for

active sonar will be just as hostile as it is for passive sonar, complicated by the shallow environment reverberation, and high and variable ambient noise. False targets will abound, and there will be a good deal of wasted ordnance, as there was in the Falklands War. The shallow environment for a campaign model, like ASSET, is difficult to model properly to simulate the real world.

The limitations on the battery will force snorkeling at various periods allowing detection by passive acoustic buoy fields and other passive ship borne sensors. The proximity of the non-nuclear submarine to the surface while making noise from its diesel engine will make it extremely vulnerable to detection. This feature must be modeled in ASSET to exploit the vulnerability.

D. PROPERTIES OF AN ADEQUATE MODEL OF THE SURFACE GROUP-SUBMARINE INTERACTION

Next, we consider what would be involved if ASSET were to contain a model of the interaction between the submarine and the surface group, including its ASW screen. For example, if the scenario to be examined is that a task force or battle group has to go into an area that has 2 to 5 submarines deployed at unknown locations off of a foreign coast, then we are likely to be curious as to the vulnerability of the ships that we send. We may plan to send in advance submarines and MPA to locate and destroy as many as we can in a fixed period of time, before the carriers arrive, and continue after they are on station. If a submarine closes to the critical range, we have (over a good number of iterations) a fairly good idea of how susceptible the formation is to attack, and how effective our pre-arrival attrition was. While this may not be satisfactory over a prolonged scenario by not allowing multiple submarine-surface interactions, it may be sufficient to a tailored specific scenario, if the enemy's victory hinges on getting

close to a ship to take a shot. To bring this interaction into ASSET many assumptions have to be made on the nature of the approach and the attack. As an example, imagine how a submarine would make a torpedo attack on a task force or battle group:

- The submarine detects the battle group acoustically. At this point, the submarine makes the determination whether or not the group can be caught, let alone attacked. In the case of the conventional submarine, this decision is much more critical, since catching up might mean the unacceptable expenditure of most of the energy in the battery. Since ASSET does a pursuit calculation knowing the preset transit speed for the surface formation, the submarine's decision will be perfect, which is unrealistic.

- The submarine begins the pursuit. The choice of course to pursue is important since the detected unit of the formation may be on the "fringe", and the direction of course may not lead to the heart of the formation. At some point, acoustic counterdetection will be possible, in which case the formation may become alert to the approach of a submarine. Also, the submarine will most likely choose to visually identify the unit(s) that he is approaching. Putting up a periscope may subject the submarine to some form of nonacoustic detection and also increase the probability of active sonar detection.

- As the submarine approached the group, the submarine would try to avoid the detection range of any outer screen ships, although he may not be aware of the presence of every unit. Consequently, a very slow approach may be dictated. In combination with that would be the avoidance of the first line of defense, the MPA deployed from the ships. The sensors that they would employ would be both acoustic (dipping sonars, sonobuoys) and nonacoustic (magnetic

anomaly detection, radar, ESM, and possibly Lidar in the future). Given certain ocean conditions and the location of the submarine relative to shore, acoustic and visual conditions may be poor for detection. The effective sweep width of the nonacoustic sensors on the aircraft is highly variable, and at least extremely depth dependent. Given one aircraft against one submarine and given detection has occurred, some value of the probability of kill would need to be available for use in these models to compute the combat result, assuming these values have been computed using practical data.

- Assuming the submarine is able to pass beyond where the aircraft is patrolling, the next gate would be to pass through the outer screen of surface ships, now that the submarine maybe within detection range of one or more units. If the units are searching passively, the searching units position becomes a guess for the submarine, as well giving the surface ship a low probability of detection. If active sonar is being employed, the submarine will have a very good idea as to the position of the ships. Since they are closer to the center, it will be harder to avoid them than the aircraft. If they detect, one should assume the detecting unit and possibly others close by would be tasked to intercept and destroy the incoming submarine, along with a close MPA. The main body of the task force or other high value units in the formation would also move away from the submarine datum. Computing this probability of kill would be a task. Would their collective efforts make them more effective, or is it possible that they could mutually interfere with each other, making the collective attack worse than if just one of them had attacked? Also, the cornered submarine may decide his most effective attack is at this point, taking out one or more of the attackers. Even if successful, it is not likely that the submarine would be a threat to the main body.

- Again assuming no detection, the submarine would continue into an inner screen of ships and helicopters employing active sonar. It is tighter than the previous screens. The analysis problem is the same as that for the previous layer. How is the post detection combat resolved? To allow the probability of kill to be equal to the combined Pk assuming independence would not allow for interfering ship noise in the water. On the other hand assuming interdependence would understate the effects of coordinated ASW and the possibility of cutting off escape routes and repeated attacks.

- Finally, if the submarine gets to the high value unit and shoots torpedoes, the post-attack prosecution at the "flaming datum" must be taken into account. The submarine's escape from the battle group or task force will be much harder than his approach. Many or most of the ASW ships will have to use active sonar search continuously against the non-nuclear submarine threat.

The above sequence shows the extreme complexity of minimum modeling of the submarine actions against a surface formation. Even in this brief example, a great deal of other detail has been glossed over. Communication, coordination, and weapon limitations are also often important.

In its present form, ASSET is unusable for surface formations or SURTASS ship interaction analysis. With no threat to it, the attacking submarine is free to fire its entire torpedo inventory into the formation, and then go back home for another loadout. Since the MOE in ASSET is the number of successful approaches, recorded when a submarine reaches a critical range, the ASSET model's submarine can attack, go away, re-detect, and come in and repeat the attack. Each re-detection is counted as an approach. Given a modest detection and communication capability, this MOE would only approach a realistic value

for formations with no defensive capability. Some scheme to represent attrition and evasion of both submarines and surface formations is needed if ASSET is to be sufficiently valid to be credible.

E. ALTERNATE WAYS TO TREAT THE SUBMARINE-SURFACE INTERACTIONS WITH ASSET

There are a few ways to better model the interaction. All involve some degree of changing ASSET's code, and as expected, the more realistic the interaction that is desired, the more complex the task of altering the code. The modifications cover many extremes from keeping ASSET mostly as it is to modeling all units. The proposed changes include: use lower level models to "feed" ASSET the probability rules of the interaction; stop the interaction at the first detection, by either the submarine or the surface formation; model each unit in the formation, including realistic ASW capabilities; and finally keep the formation as a single unit, but give it the aggregate capabilities of all units in the formation.

In the "hierarchy of models", smaller scale models feed into larger scale ones so that both the speed of analysis is kept high and the detail that is in the lower level model can be used in the higher level one. Once the submarine reaches the critical range to the surface formation, the process by which we arrive at the outcome of the battle is irrelevant. We are concerned with:

1) Was the submarine sunk or damaged or escape?
2) Was a high value unit sunk?
3) Did any other surface units get sunk and how many?
4) How many weapons has the submarine expended?

5) After detection or flaming datum, what is the presumed position of the submarine for MPA or other ASW forces to react to?

If there was a lower level model that would output answers for the specifics of the battle, then the obvious answer is to use that method for the combat resolution. The problem then arises of how specific the analyst needs to be for the campaign results. If he does not care about details such as how the surface formation is arranged, the propagation paths available in the local area, or ambient noise levels, then the running of the lower level model to get statistically significant data may prove too laborious a task. The approximations may then fall on ASSET so as to ease the job of the analyst in the data search and input. Adding any routines to ASSET other than the simple probability answers to the questions above will make the entire program much slower, and the results more questionable due to the new built-in assumptions. Therefore the additions must be minimized, the most effective only implemented.

On the other end of the spectrum would be to avoid the entire issue of how effective the submarine was against the surface group and vice versa. If the MOE of number of approaches to the critical range is sufficient then that may be all that he or she needs to know. The major correction to the scenario would have to involve when the program would halt an iteration and go on to the next one. If the goal of analysis is to determine the vulnerability of surface formations to a local submarine, the easiest fix may be to simply stop the iteration at the point at which the critical range is reached, saving as a data file the range at which initial detection occurred, time of initial detection and at critical range, and the axis from where the threat finally occurred.

If either of these extremes are still not satisfactory, then a series of compromises is required. One idea might be to make each single surface unit a "super submarine" with almost all abilities, and then set up a formation of these units under a Commander. This separate central Commander object would be similar to the SUBOPAUTH or ASWOC in the ASSET model. This object would control the ships and aircraft in the task force/battle group, control the allocation of combat assets to a threat, any specifics on MPA attached to the group, just as the other senior level command objects do. Each ship would be essentially a non-submerging submarine with detection, communication, and combat capabilities, as well as the capacity of being destroyed. The detection networks could be set up to report contacts, even false alarms, to the Commander object for allocation to combat. The problems with this particular method would be the degree to which the program would be slowed to account for all the units, and the vast amount of setup required, including ships locations within the formation. Also, there is no mechanism for mutual acoustic interference, which would hinder detection by some units in the formation. There is no good way, as mentioned above, to determine how effective joint attacks would be against the closing submarine. If one knew all the unit-on-unit Pk's, then an approximation could made using the half and half rule or some other method to show the attack is not completely without mutual interference.

Another compromise would be just to make the surface formation a single unit, for instance a carrier, representing the entire group and give it the composite abilities of all members of the group. If the user subscribes to the theory that without the carrier (or amphibious ship or merchant) the group is essentially useless, then sinking the "formation" would mean the destruction of the carrier,

and the group would no longer count. In truth, the remaining vessels would have a great deal of worth, and still may draw off enemy submarines. The abilities of the "super-carrier" would be hard to determine however, on the order of having to run a lower level model to fix the groups defensive strength. Detection capabilities of the super unit would be at best large cookie cutter model, or sections of a circle that would be difficult to incorporate in the model as data entry.

F. CONCLUSIONS

There is probably no good way to model the surface interaction with ASSET. The best way is to get inputs from lower level models if available and just attrite the surface groups and submarines on each interaction. The easiest way is to alter the code to end an iteration of the simulation on a submarine approach to the critical range, recording the circumstances of the interaction. To make any other compromises may be satisfying to the user but would not be operationally accurate.

The solution to the surface interaction for ASSET is a combination of the best and the easiest ways. Give the user a choice as to how he wants the interaction resolved in the umpire menu; either choose to stop the interaction at the point of first detection or define the surface formation with the answers to the questions of ASW capability asked earlier. This way the user can look at the attrition process prior to the interaction, or look at multiple interactions with his own data of ASW capability. Since there exist many analysis estimates as to how the battle group will perform from many, many research institutions, any of those data inputs could be used in table lookup form. The combination of the two methods

would keep ASSET viable, if both processes could be incorporated into the program since either would be "good enough" in a certain analysis.

IV. METHODS OF DETECTION

Detection is the single most important phase of the ASW battle. If the submarine remains undetected up to the time of the attack, then its mission most likely has been a success. For that reason alone, each ASW platform has multiple methods to search and detect submarines. Some do no more than confirm the initial detection by another sensor, but all attempt to verify that a submarine has been found.

The struggle for new, secure and foolproof methods of submarine detection have been ongoing since early in the century and has been the direction for major funding since World War II. Concentrated efforts continue, with esoteric, high risk projects studied to make the oceans transparent. Acoustic detection is still the best area search method available to the Navy and undoubtedly will be the prominent method in the future as well.

In a complete simulation, the detection methods used by all platforms on both sides would be completely and realistically depicted. ASSET uses only passive sonar for acoustic detection, and communications interception for nonacoustic detection. Satellite radar is available for the detection of surface groups for use by submarines, but satellites are hard to deal with since many of their parameters are classified to a high level. Many methods such as magnetic anomaly detection (MAD), lidar, and bioluminescence detection are waiting in the wings, but may be impractical and insignificant in a computer simulation, given the amount of detail that some methods may require, which would greatly slow computation routines . Detection is such a significant part of the battle that it must be continually

reviewed to see if it is represents detection in the best way possible, and if a good method must be represented, then the detail will have to follow.

This chapter will attempt to focus on the numerous detection methods that may be covered in a campaign level simulation. Some methods are completely necessary, such as some sort of conventional active sonar model on surface ships. Others, such as radar, can be subverted by a target submarine, and just may not be worth the effort of installing in the program. Some may just fall into a middle ground where they are good to have, but do not have a significant impact in the simulation.

A. SUBMARINE BASED DETECTION METHODS

Submarines have three major sensors: sonar, radar, and electronic support measures (ESM). The submarine's major and most effective sensor is the passive sonar system, and though she can go active, rarely does for fear of counterdetection of the energy that is put in the water. There is radar, used normally while the submarine is on the surface, which is can be even more detectable than an active sonar transmission. Finally, there are electronic support measures receivers onboard, allowing for detection of electromagnetic signals throughout the spectrum. The three allow give the submarine enough flexibility to be quite a formidable sea-denial platform.

1. Sonar

A submarine's sonar generally manifests itself in a forward hull array, usually cylindrical or spherical in shape, and sometimes in more advanced types, a

towed line array. The forward array has both active and passive capabilities, while the towed array is strictly passive.

Like the rest of the objects in ASSET with a detection capability, it will be necessary to enable the submarine to go into an acoustically shallow area to conduct operations. From this perspective we must look at the implementation of the passive sonar model in ASSET and see how it might be adapted for shallow water.

a. Passive Sonar in ASSET

To understand the passive sonar environment, it is helpful to review the passive sonar equation to see where deep water assumptions are affected by a shallow water environment. We, of course, desire to keep the data entry and assumptions to a minimum, and to try to use as much of the existing ASSET framework as possible.

The passive sonar equation is:

$$\text{SIGNAL EXCESS} = SL - TL - (NL - DI) - DT$$

where SL = source level of the noise

TL = one-way transmission loss or propagation loss

NL = noise level, the power sum of self noise and ambient noise

DT = detection threshold

DI = directivity index

For easier use by ASSET, this is expressed as:

$$\text{SIGNAL EXCESS}(t) = \text{FOM} - \text{TL}(\text{Range}(t))$$

where FOM is Figure of Merit and equal to:

$$\text{FOM} = \text{SL} - (\text{NL} - \text{DI}) - \text{DT}$$

By the above equations, FOM is time invariant, and is a simple number for each unit in each region computed from the specific unit parameters that the user gives in the platform definition phase. The ambient noise level and the transmission loss depend exclusively on the environment. Signal Excess is time variant depending on the range between searcher and target at time t. Also as convention, signal excess is assumed to have uncertainty, and is a normally distributed random variable with mean zero and standard deviation σ. ASSET in the end comes up with a probability of detection function, but puts it all together by Monte Carlo simulation rather than analytically. The simulation assumes detection, if and only if actual signal excess exceeds zero.

The propagation loss, or transmission loss is the key to ASSET's detection model, and certainly the single most difficult bit of information for the analyst to pin down. Obtaining transmission loss curves out to one hundred miles is not easy to do, unless you are shooting to make a cookie cutter detection model by zeroing out all loss values to the range you desire, and high values from then on. The need for a complete, accurate transmission loss curve will most likely require running one of the standard Navy models, such as PE (Parabolic

Equation) or ASTRAL for range-dependent losses or RAYMODE for range independent losses. All are now available in some form on personal computers, such as many shipboard desktop calculators, and are fairly easy to use. For shallow water transmission loss computations for the 100 hertz to 2.8 kilohertz range, an empirical model COLOSSUS II is available and is based on some one hundred thousand observations in waters less than 400 meters deep. Unfortunately, there are so many caveats in the proper use of the models that it may require that the analyst gain some degree of expertise in tactical oceanographic predictions prior to using these models to obtain a transmission loss curve.

The environmental regions in ASSET are defined to be homogeneous, having the same transmission loss and ambient noise throughout the region. The transmission loss curve for a frequency and the ambient noise value are assigned to a user defined region. There is no variation in bearing, and there is no relationship to the geographical land mass features. The land, in essence, floats above the water.

b. Problems in the Passive Sonar Model

As we mentioned in Chapter I, one of the criticisms of ASSET is that passive sonar is not modeled the way it would be used operationally. The nature of sonar arrays, especially towed arrays, favor the searcher using the highest stable frequency available from the source for tracking purposes. This is because the beamwidth of the array is inversely proportional to frequency monitored. Therefore, the higher the frequency of interest, the tighter the beamwidth, and the more accurate the bearing from the tracker. This process results in a flexible

method of tracking a contact. The target will radiate many frequencies, but it is the highest stable one that he will be used to track. If that frequency is lost for some reason, then the next highest stable frequency will be the one used. For example, assume the target radiates on many tonals, but the signal excess on the one tonal that is specified in ASSET drops below zero while another remains well above zero. ASSET will cause the searcher to lose all contact while a human tracker will simply shift to the other tonal, which although may not be as accurate, would still let the searcher maintain track. ASSET avoids this shifting process by allowing only one radiated frequency from the noise source. This assumption allows the target to be tracked on one frequency at a fixed source level (SL), thereby keeping the FOM calculation for that target constant.

After the modifications by Peng-tso Chang [Ref. 16], a source's most detectable frequency was allowed to vary with the environmental region. This modification was for the better, although still not as good as "real life." Chang's improvements would allow the track to be resumed if both target and searcher crossed into a new region, assuming the transmission loss was less than that for the previous frequency in the previous area.

Optimally for the tracking routine, a whole list of radiated frequencies could be used to define each platform, and then the environmental areas would be defined at each frequency for the transmission loss. The argument at this point becomes how to reflect bearing errors due to the large beamwidths from tracking at lower frequencies. If this approach of multiple frequencies was to be used, it may then require the Detection Reports Edit Window to be linked with the frequency list for that scenario and environmental region.

Another sketchy implementation in ASSET is the subject of homogeneous water masses and their relevance in a shallow water environment. This may be a fine assumption in the open ocean, but it is in error as soon as a ship is close enough to shore to "see" non-symmetric ambient noise and shallow water transmission loss effects. Although the user can generate regions of any size and boundary complexity, the homogenous aspect of the region do not allow any sort of variable environment. The great advantage of using the standard Navy transmission loss models is that ASSET does not have to care at all about bottom types, salinity gradients, or a host of other problems that a range dependent model could take care of. This is just another application of the hierarchy of models, applied to a numerical data entry for transmission loss. From the assumption that the computed transmission loss is accurate and the user has chosen the correct models, or series of models (and this may be the largest assumption), we do not have to worry about the "floating land" or changes in the water transmission characteristics. What becomes very important is the horizontal directionality for both transmission loss and ambient noise.

Below is Figure 8, showing the transmission loss contours about a shallow water site. It shows that while we may be able to compute a single transmission loss along one of the radials, there is little correlation between radials and they do vary significantly, enough to upset the passive sonar equation, depending on the direction the ship is listening. Noise level, as stated above, is the power sum (the sum of two logarithmic levels) of ambient noise and self noise. Self noise in ASSET is a fixed quantity for a ship, and is a user defined value. Ambient noise is specified for the water mass in the region definition phase. Like the transmission loss curves, ambient noise in a shallow water environment is

highly variable in a horizontal direction. Figure 9 is a diagram showing the extreme variability in direction in the middle of the Pacific.

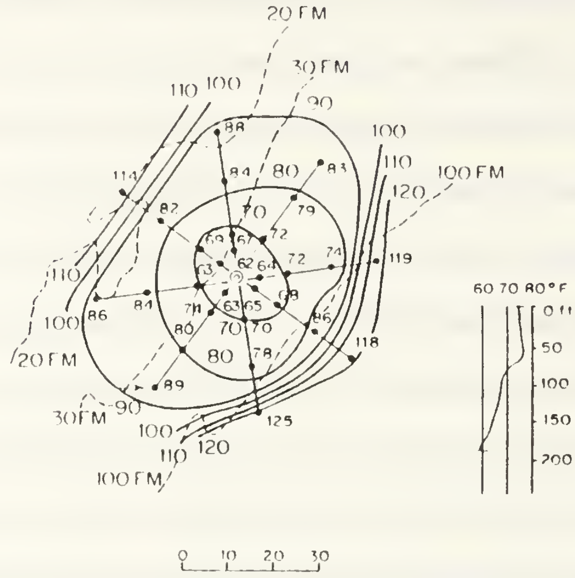

Figure 8. Transmission loss contours about a shallow water site [Ref. 17:p. 182]

Unlike transmission loss, ambient noise is not nearly as predictable, depending on shipping and industrial noise, wind noise and biological noise. At any given time the combination of these factors will determine the ambient noise level. There are ambient noise prediction databases, such as DANES, which aid in the determination of the ambient noise levels. Using this kind of information would most likely be the only way to determine reasonable estimates as to the noise level. There is one final consideration in the ambient noise question. Since shipping noises are a major part of the total noise level, thought must be given to how this noise would change if there is conflict. An analyst should reasonably expect to see less major shipping after one or more has been sunk in the area, so all predictions of ambient noise based on historical data may be high, as other ships and pleasure craft exit the area.

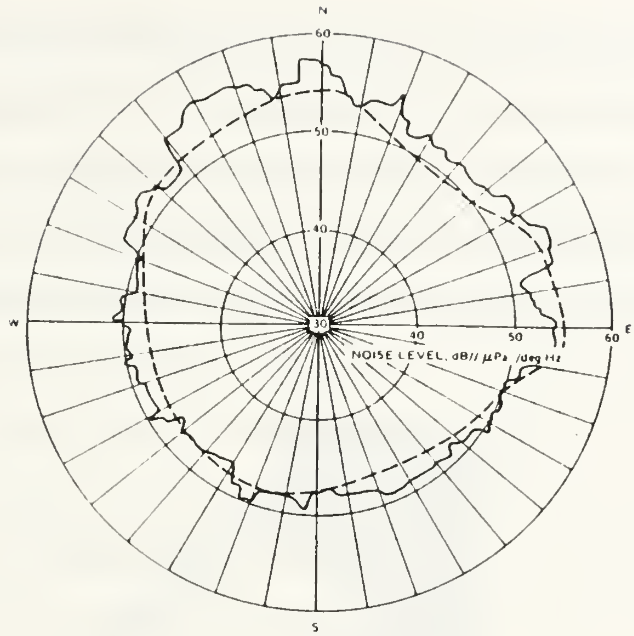

Figure 9. Horizontal Variability in Ambient Noise [Ref. 18:p. 5-21]

The problem remains of how to implement all of these shallow water considerations. Any correction to the present system will entail much more data entry just in the most basic assumptions how to model a shallow water environment. The most equitable solution for an off-shore area may simply be to take any user defined environmental region and divide it into quadrants as shown in figure 10, toward the coastline, away from the coastline, and along the coastline in either direction, and simply use the biggest transmission loss and largest ambient noise for each quadrant. This division could occur in software where the course of the submarine, the direction that it is heading, determines the noise field and transmission loss that its sensors would be subject to. The other method to implement this division, and the one that would take no manipulation of the code, would be to physically divide into subregions a desired region into the quadrants,

and have the user define for each the transmission loss and ambient noise. This process would, in effect, try to approximate a non-homogeneous region, by forming it from multiple, different, homogeneous regions. This division would require that the analyst do a great deal of research into the environment, however, which could be the sole reason that ASSET would not be used.

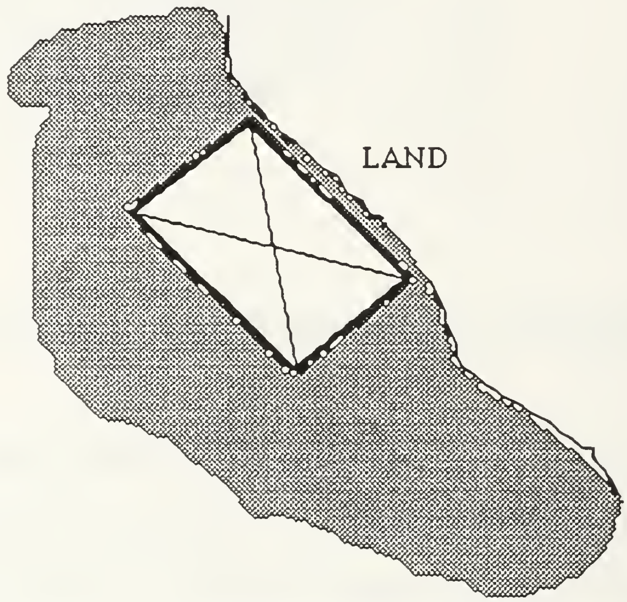

Figure 10. Example of forming quadrants of an acoustic region

A much more simplistic approach would be to define a very narrow region close to the shore and give in uniformly the worst transmission loss and largest ambient noise. This would be a "pessimistic" approach to the analysis, but also would enable simple shallow water modeling without any modifications to the code. It would also allow the user to perform sensitivity analysis, if desired.

Finally, the problem of depth changes becomes apparent with the advent of a non-nuclear submarine. In computing the transmission loss curves using the standard models, it is crucial to define both the target depth and the

receiver depth and the frequency of analysis. In ASSET these depths make no difference to the model; all it is concerned with is the transmission loss curve between the source and receiver. If the simulation is to contain a non-nuclear submarine that has to change depths, however, consideration has to be given to other transmission loss curves for the multiple depths. The recharging of the battery using the diesel engine is the noisiest evolution that a non-nuclear submarine can perform, and it does so right at the surface, probably within a surface duct that would allow long range detection by opposing platforms. At a minimum, for the diesel submarine, computation of transmission losses at both periscope depth and a transit/attack depth is necessary for proper modeling of detection for both the submarine and opposing units. Implementation of a depth changing submarine may require the computation of possibly three transmission loss curves, one for periscope depth, one for submerged above the layer, and the last for submerged below the layer. By the principle of reciprocity, the transmission loss could apply to submarine detection or surface detection assuming the same frequency is the same in a homogeneous area. Also, a submarine operating "script" would have to be defined to direct the submarine to be at particular depths at certain points in its operation.

The bottom line in implementing shallow water losses with a non-nuclear submarine in the area is that a lot more legwork will be required on the part of the analyst running the model. Accurate transmission loss curves will have to be generated using the most applicable oceanographic models available for both multiple regions off shore and multiple depths for the conventional submarine. No matter the simulation, if the acoustic detection is required to be accurately modeled, then the analyst must be willing to forgo simple detection

models and do a great deal of preparation prior to running the simulation. It can be done in ASSET, but will not be easy.

2. Electronic Support Measures (ESM) and Radar

Much like the police radar warning devices in automobiles, the ESM receivers onboard ships, submarines and aircraft give the owner a great deal of information about current threats. Unlike cars though, this information is very specific, down to signal strength and transmission frequencies. For a submarine this information could determine life and death, simply by notifying personnel that a mast such as a periscope may be exposed to air or surface based radar.

According to the 1992-1993 *Jane's Fighting Ships*, virtually all submarines carry ESM receivers as a countermeasure to radar, even the old Foxtrots sold to Libya. From this information, it would be a waste of time to install a complicated radar detection model, since the searching unit may get one or two sweeps at most on a periscope and then lose contact. Often the early warning receivers onboard the submarine would be able to point out operating radars long before the searcher came within range where he was able to detect a mast. Even submarines passively copying the broadcast would lower the mast and try to copy it later. For so few detection opportunities a radar detection model would be a waste of computational time.

Radar's use for a submarine would not be for detection, but rather for the detection of surface groups and other submarines, followed by homing in on the source as a beacon and then attacking when within range. If the assumption can be safely made that surface formations will not remain in emissions control, then this method should be entered into ASSET to bring in a legitimate

vulnerability to surface formations. This process would require assigning a radar object to surface ships with characteristics of some period of time between transmissions, the length of transmission and the range to which it could be detected. The range normally wouldn't be a constant value, but that approximation would suffice out to the visual horizon of the radiating platform, as a safe assumption.

B. SURFACE SHIP BASED DETECTION METHODS

The units in a surface formation have to a large extent the same types of detection systems as submarines, but are very apt to use active sonar for detection of submarines and possibly radar to pick up an exposed mast. In a regional type of conflict. the low level of noise from diesel submarines will likely force major use of active systems in a regional type of conflict rather than the traditional passive systems. This use can both detect and alert the submarine to the possible location of the surface formation.

The assumption in discussing any sensors on the surface ships is that the surface formation will be given some interactive capability eventually. This is not expected to happen due to the complexity of the additions that would be required. This analysis may be helpful in other contexts, in case ASSET in a future version or other simulations decide to take up this problem

1. Active Sonar

Active sonar is quite different from the passive systems in ASSET, in both reality and possible implementation. The form of the equation is similar and the concept of a transmission loss is the same, but generating a signal to get a

return adds in many variables including the target strength, which is dependent on the hull shape and aspect, the noise level in the ocean and the reverberation level, which are dependent on the power level and the environment.

The active sonar equation is:

$$\text{SIGNAL EXCESS} = SL - 2TL - (NL - DI) - DT + TS$$

where SL = source level of the noise

TL = one-way transmission loss or propagation loss

NL = noise level at hydrophone

DT = detection threshold

DI = directivity index

TS = target strength

Like the passive sonar equation, active sonar could be treated as a fixed term, FOM or figure of merit, and a range dependent transmission loss term:

$$\text{SIGNAL EXCESS}(t) = FOM - 2TL(Range(t))$$

where FOM is Figure of Merit and equal to:

$$FOM = SL - (NL\text{-}DI) - DT + TS$$

This series of equations are true if the environment is not reverberation limited, in which case the active sonar equation becomes:

$$\text{SIGNAL EXCESS} = SL - 2TL - RL - DT + TS$$

and

$$\text{FOM} = SL - RL - DT + TS$$

As there are computerized models to predict the transmission loss for the passive sonar equation, so there are also models for the active portion as well. ACTIVE RAYMODE, which is range independent, will provide the user not only with a transmission loss but also estimations into the reverberation levels if needed. DANES in the noise limited case will still be able to provide the ambient noise level for the active equation. Detection Threshold, Source Level, and Directivity Index are all reference values for the particular platform being studied.

To implement an active sonar model in ASSET is going to require either extreme simplification in the model by using circular probabilities of detection or a great deal of off line analysis and preparation by the user. The big variables in the passive sonar equation were the transmission loss and the ambient noise. In the active equation, transmission loss, ambient noise, reverberation noise, and target strength are all variables and positionally dependent. Also, a ship may be reverberation limited in a bottom bounce mode, but may be noise limited in a direct path mode. It is easy to make passive assumptions, but active assumptions may be more far reaching.

Target strength is dependent not only on the size and distance of the target, but also on the aspect of the target. Figure 11 is an example of a "butterfly" diagram which shows aspect dependence on target strength. Some assumption would have to be made on target strength since ASSET is not concerned with tactical details. One approach may be to make target strength a

normal random variable about the bow aspect target strength, with the built in assumption of a closing submarine trying to minimize its sonar return.

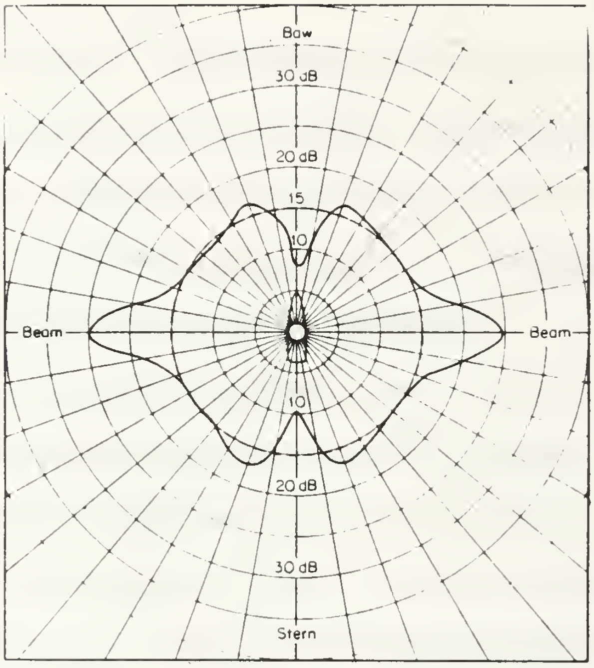

Figure 11. "Butterfly" pattern of the aspect variation of submarine target strength [Ref. 19:p. 311]

Determination of noise limited performance and ambient limited performance in a shallow water environment may simply be too complex for the simulation. Like passive sonar, going active toward a shoaling coastline will produce a much different signal excess than in a homogeneous deep water environment, due in part to reverberation, and in part to transmission loss.

For the user this will mean that to implement active sonar, certain sacrifices may have to be made. The user can analyze the scenario using the worst case target strength, transmission loss curve, and reverberation limited noise

in a specific transmission mode in a certain user-defined region. The values for these variables which he can obtained from the standard Navy models, and the simulation can be repeated changing the values to derive some feel for the sensitivity of the variables. To input more than one set of active sonar data per user defined region may confuse the user in worst case analysis, and just bog down the process of getting the simulation up and running.

2. Radar

As mentioned in the submarine model, there is no real need for a radar detection model based on trying to catch a submarine at periscope depth if it has some degree of charge in the battery. While there may be specific radar search plans that allow surface formations to detect non-nuclear submarines in a more covert fashion, if the submarine tries to maintain a war footing and uses mast discipline and does not snorkel in enemy occupied areas, then gains from radar use will be minimized. All the submarine has to do is lower the mast, removing the object that can be detected, and move away. Where a detection should occur is in a scenario where an exhausted battery in a conventional submarine may force a snorkeling operation within the detection range of either ship or aircraft. In such a case, it would be reasonable to assume that if the submarine were required to snorkel within some user defined detection range for the radar, then either the encounter process should be forced to begin at that point, or simply treat the submarine as sunk. Since the submarine will be limited to near surface operations by the diesel operation, the submarine's position would be quickly determined, and snorkeling within the radar detection range should be treated as a kill for a surface formation with ASW offensive capability. If the surface formation does

not have the periscope radar, the submarine should be allowed to snorkel at leisure, at least until it comes within range of some detecting platform. If the group has the radar but no weapons, then a message should be sent on the C3I network.

3. Electronic Support Measures

Much as the submarine needs an ESM receiver to determine the level of threat to its safety, surface ships also benefit from the presence of such ESM receivers. Unfortunately, the only real threat in ASSET to the surface formation is the opposing submarine, which is unlikely to radiate on the radar. What the submarine will do is to communicate when it has a contact to report. This is now detectable in ASSET by HFDF sensors and ELINT satellites, but if the surface formation were to eventually gain interactive capabilities, a sensor object keyed to listen for this transmission would be required. The result would be a detection report from the surface unit, exactly the same as that from the HFDF network or ELINT satellites.

C. MARITIME PATROL AIRCRAFT DETECTION METHODS

The MPA is one of the more potent threats to the submarine, not only because of the multitude of sensors carried onboard, but also because if its high speed relative to the submarine. This platform, more than any other has become the test bed for many of the nonacoustic detection methods used in the U.S. Navy because of the areas that it can sweep out by both altitude and speed. Some of the nonacoustic systems that we see aircraft obtaining include Magnetic Anomaly Detection (MAD), periscope detecting radar, lidar, and bioluminescence.

It is still the acoustic systems that the aircraft rely on for the large area detection however.

1. Sonobuoys

Sonobuoys constitute the major focus of the acoustic detection method that aircraft employ. These sonobuoys come in both passive and active types, and are designed to operate in patterns to maximize both detection opportunities and directionality of the buoys. The buoys themselves have a fairly large beamwidths, so the patterns become necessary to localize the submarine in a large general area. ASSET only models sonobuoys by passive fields of uniformly placed buoys. Any advantage of these tactical patterns is negated. Richard Shaffer covered and made suggestions for improvement in his thesis at NPS [Ref. 20].

Active sonobuoys, used mostly for a final localization after passive detection in order to attack, are complex in terms of where to drop, when to drop, and how deep to drop at. These buoys could act as active sonar objects that would detect submarines after the passive localization. Data entry at this point becomes laborious for the analyst for a process used only in final localization, and a sacrifice in computational speed would likely be suffered for a model that is not necessary.

2. Nonacoustic Sensors

As we mentioned, nonacoustic sensors are a big part of aircraft operations from mostly radar and MAD. Lidar and bioluminescence detection

systems are not deployed yet although they will form two new major means of submarine confirmation.

All of these methods are good up to a point, and are used to accurately fix the position of the submarine prior to launching a weapon for a submarine kill. Since these methods are not generally effective until after the submarine has been localized to a specific area by the passive buoy methods, these methods are also cumbersome in the modeling process. For limited modeling controls, the installation of large sections of code for results that could be incorporated into the MPA - submarine Pk's is a waste of time for both the programmer and the computer, not to mention the user who must obtain hard to get information such as magnetic moments and water clarity measurements.

V. SUMMARY AND CONCLUSIONS

A. SUMMARY

Three subjects have been covered of the utmost importance in upgrading ASSET: the conventional submarine, the surface group and its ability to interact in the model, and the addition of active sonar and ESM in detection methods.

1. The Conventional Submarine

The conventional submarine is very different from the nuclear submarine in vulnerabilities, capabilities, operating regions, and tactical employment. To model the conventional submarine using the nuclear submarine model would overestimate its power plant and give it the ability to remain indefinitely submerged, only coming to periscope depth for communication reasons. If a simple indiscretion rate model is used, i.e. going to periscope depth to snorkel some fixed percentage of time, then no consideration is given to the limitations of the battery at a number of different speeds. The heart of the conventional submarine is its power plant. The battery output characteristics must be the first priority in modeling, and from this the detection and communication capabilities can be determined.

A simple model for the power plant operations was proposed in Chapter II based on actual performance specifications from the Type 209 (1200). The speed versus submerged time curve was normalized to remove the specifics of that particular submarine. Other speed versus submerged time curves for other submarines can be obtained by reversing the process with the specifications of the desired submarines.

2. The Surface Group

The surface model in the initial version of ASSET is inadequate. Presently, all that occurs is a submarine detects the group, the submarine moves into a user defined critical range, fires a portion of its weapons and then moves away. The surface group has no chance to detect first, and no reaction to this attack, not even after a sinking or being alerted to the presence of a submarine in the area. The submarine may move in for a re-attack, if it re-detects the group. The measure of effectiveness of this approach is how many times the submarine reaches the critical range. In this attack, move away, re-attack, move away scenario the MOE is a useless statistic. As many analysts have pointed out, some other method of interaction between the submarine and the surface group must be produced.

ASSET needs at least rudimentary capability of the surface group to defend itself, communicate with ASW assets, and if all else fails, to vanish when sunk. The ability to communicate in an encounter would be fairly straightforward to incorporate. Attrition of units is much more difficult, and there are not many ways to accomplish this. The first method would be to use data from the lower level engagement models to determine the outcome of the interactions. In this way, submarines and surface ships can be sunk, and determination of damage to high value units can be ascertained. The assumption is that the submarine would always would detect the surface unit first and the surface unit would be in a primarily ASW defensive mode. The problem is finding an adequate lower level model, giving it all the relevant data for the encounter and then extracting the

statistics needed for ASSET. Even these results may need to tabulated for ASSET to take into account the many variations such as approach angle.

The second method would be to model each unit in the formation, and have them all under the control of a senior object like the MPA's ASWOC. Each unit would have detection capabilities, communication capabilities, and could be sunk. The unrealistic part would be in mutual acoustic interference, a need for formation deployable MPA to form the outer screen, and finally one-on-one Pk's to resolve individual combat.

The third method would be to keep the surface formation an aggregate unit, much as it is now, but give it collective offensive and defensive capabilities of the formation including detection capabilities. This grouping would be difficult to fix values on; surface force detection range alone would have to be a simple cookie-cutter model since it would take a study unto itself to determine multi-unit detection range for specific environmental and operational conditions.

Finally, the fourth and easiest method would be to leave the formation almost as it is, but change the code to end an iteration when a submarine reaches the critical encounter range to the formation, thereby ducking the issue of the group's response. This again assumes that the submarine make the initial contact, but avoids the need to put in any other modifications such as communication, detection, evasion or sinkings. This simple fix has many weaknesses, for example, if there were multiple surface formations in the scenario, but might give ASSET some utility for campaign analysis.

The solution to ASSET's interaction problem is to simply give the user a choice of the two best and easiest fixes: either stop an iteration when the first detection occurs between the submarine and the surface group, and record the

pertinent data, or have the user define the surface group with the pertinent questions as to it ASW strengths and vulnerabilities listed in Chapter III. Both ought to be implemented within ASSET, with the user telling the program's umpire which way he desires to go. The modifications to the code should be slight, with a good amount of flexibility added in with little work.

3. Alternate Methods of Detection

Each type of unit has a preferred method of detection that it uses to find opposing platforms, and currently all happen to be forms of passive acoustics. There are significant other means of detection that should be considered though to make the campaign simulation more realistic.

For submarines, the major sensors are the passive hull arrays and possibly towed arrays. The submarine uses these almost exclusively. It almost never uses its active detection capabilities for fear of counterdetection by an enemy. The passive model needs some improvement to allow it to model a shallow water environment, including assumptions regarding how to treat variability in ambient noise and transmission loss. The submarine can also monitor the electromagnetic spectrum passively through ESM receivers in the periscope, which in most cases would void the use of radar by aircraft and ships for submarine detection. What the ESM receiver will do for the submarine is to allow it to follow a bearing into a surface formation or submarine that may happen to be radiating. If one assumes that a battle group cannot remain under constant emissions control (which is especially possible in night carrier landing operations), then a submarine can use its ESM receiver to home in.

The surface ships, while using primarily passive acoustics now, will most likely find that against a small quiet submarine on the battery, active sonar is the only feasible way to search or screen. While detection may be complicated by a shallow water environment, the active model is a necessary addition since that may be the only detection method that actually provides a reasonable detection opportunity. Unfortunately, due to the many variables in active sonar that do not exist in passive sonar, the best that can be done is worst case analysis for a region, with the worst transmission loss, target strength, and noise level assigned to the entire region. The incorporation of any sort of horizontal variability within a region would be too hard to collect the data for and would likely confuse the analyst and the analysis.

Radar is unnecessary in the surface ship model since it is unlikely that with a good ESM receiver, the submarine is going to allow itself to be detected with proper mast management procedures. There is some need for a model that would show that the ship had a radar energized however, since this signal could be detected and tracked to lead the submarine to the surface formation. Implementation of this could be as simple as setting a flag at some user defined interval to represent power to the radar, and then have all submarines that are in a certain range move directly toward the signal with some error thrown in for bearing accuracy.

The Maritime Patrol Aircraft have a good number of sensors onboard including the sonobuoys, magnetic anomaly detection, and Lidar in the future. The best sensors in terms of the widest area searched are the acoustic ones, and the others mainly assist in localization and attack. MAD and Lidar are simply not worth the trouble to alter the code for, since they are or would be used for

confirmation prior to weapons release. Computation and data would be required involving magnetic fields, orientations of ships, altitudes, water clarity, source power levels and a host of other details, that may be too hard to find.

B. CONCLUSIONS AND RECOMMENDATIONS

ASSET, despite its many documented weaknesses here and in other reports, is still quite a complete program for a Monte-Carlo simulation dealing with the huge subject of campaign-level ASW. It is very thorough, but in a Soviet-U.S. confrontational context in deep oceans, with land simply as a reference. The program needs to be brought up to date, if possible, to reflect the conflicts that would face forces in the future and the environment in which the battle would occur.

The central question is whether ASSET is worth updating. The ASW threat from numerous SSNs and SSGNs has not disappeared. We should know the risks that our power projection platforms such as carriers, cruisers, and amphibious ships will face with this kind of threat when they go in harm's way. Campaign simulations such as ASSET can theoretically provide us with an indication of the level of the threat that we may face. ASSET, through its implementation on a personal computer, and its flexibility to study almost any part of the world, makes it a good candidate for use in that kind of role.

Its limitations, especially in littoral operations against non-nuclear submarines, are daunting, however. Unless the near land ocean environment is loaded into the program in great detail, the major focus of this program, detection, including active sonar detection, will not be very accurate. Operations in quiet, deep homogeneous water is ASSET's strength and we are unlikely to be at risk there

for at least the near future. Temperature, salinity, and ambient noise will all vary greatly in bearing from a position just off shore. If a subroutine could be added that would give an accurate depiction of the shallow environment, with help from the Navy oceanographic models then ASSET may be worth saving. The tracking and communications networks and processes are nice, but are secondary to doing the best possible to model the environment in which our forces would have to fight. Likewise, the surface group-submarine interactions and the diesel submarine model suggested here are desirable, but since the vulnerability of operations and interactions hinge on detection ability of opposing units, these models are also secondary considerations to environmental modeling.

Many of the analysts desire nothing more than a cookie cutter model for the ships. That may do the job for simple models, but in a complicated environment, a complicated model for the environment would be required. ASSET should provide both for ease of use, but the heart of the program should be a quality detection routine.

Lisp is generally a difficult language, and ASSET's modularity is in question based on it being simply too hard to program. If ASSET was shifted to object oriented Pascal or C/C+/C++, then the program could be easily ported to other types of machines and altered to suit individual needs. As it stands now, the program will most likely only receive updates through theses at the Naval Postgraduate School from students intrepid enough to want to wrestle with the code.

In sum, ASSET needs a major overhaul to reflect the threats that are to be faced in the future. Its results are extremely suspect for a surface group going close to a coast, encountering conventional submarines there or along the way.

The three major subjects of this sample study, the surface group, the conventional submarine, and the methods of detection in a shallow environment, are all incompletely modeled and if not updated will limit the usefulness of ASSET. If these changes can be made with a reasonable amount of effort and without a great deal of compromise, then ASSET will be of use. Otherwise, it may be wise to build a new model that structures the program to the scenarios in which the U.S. Navy's ASW forces will be employed the most frequently.

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